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Non-Causal Video Encoding Method of P-Frame

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***Abstract*— In this paper, the feasibility and efficiency of non-causal prediction in a P-frame is examined, and based on the findings, a new P-frame coding scheme is proposed. Motion-compensated inter-frame prediction, which has been used widely in low-bit-rate television coding, is an efficient method to reduce the temporal redundancy in a sequence of video signals. Therefore, the proposed scheme combines motion compensation with non-causal prediction based on an interpolative, but not Markov, representation. However, energy dispersion occurs in the scheme as a result of the interpolative prediction transform matrix being non-orthogonal. To solve this problem, we have introduced a new conditional pel replenishment method. On the other hand, Rotation Scanning is also applied as feedback quantization is the quantizer in this paper. Simulation results show that the proposed coding scheme achieves an approximate 0.3–2 dB improvement when the entropy is similar to the traditional hybrid coding method.**

***Index Terms*— non-causal prediction, inter-frame coding, conditional pel replenishment.**

I. Introduction

Motion-compensated (MC) image coding, which takes advantage of frame-to-frame redundancy to achieve a high data compression rate, is one of the most popular inter-frame coding techniques [1]-[2]. For the H.26x family of video coding standards, a motion estimation (ME)/MC coding tool that is combined with an orthogonal transform (OT)[15]-[26], such as a discrete cosine transform (DCT), has been introduced. This tool now plays an important role in the inter-frame coding field [12]-[14], [27][28]. According to the conditional replenishment pixel method and quantization control in the DCT coefficient domain, the H.26x standards gain considerable coding efficiency and transmission bandwidth reductions by applying this method.

Conversely, we have developed a hybrid I-frame encoding method based on non-causal interpolative prediction and differential feedback quantization that utilizes the intra-frame spatial correlation [3]. To verify the efficiency of that hybrid coding method, we compared the method with H.264 in I-frames. As a result, an approximate 0.5~5 dB improvement was found by applying the developed method [3].

In this paper, a new configuration for P-frame coding is presented. In designing this hybrid coding scheme, we show that orthogonal transforms do not need to be considered as constraints.

II. Proposed Scheme

The proposed coding scheme is shown in Figure 1. In this model, MC predictive coding is first performed, and then the residual signal is encoded by an interpolative prediction (IP) method based on an 8 × 8 block [3]. We term this hybrid coding method the "MC+IP synthesis configuration".

A. Motion-compensated Predictive Coding

MC predictive coding in the proposed method is identical to that used for inter-frame MC prediction of P-frames in the H.264 video coding standard. Here, the number of reference frames is set equal to one.

B. Interpolative Prediction

The residual signal after motion compensation is coded by an IP method based on 8 × 8 blocks. The encoding matrix C used in this IP is similar to that presented in Ref. 3 except for the elements that correspond to four corner pixels of block

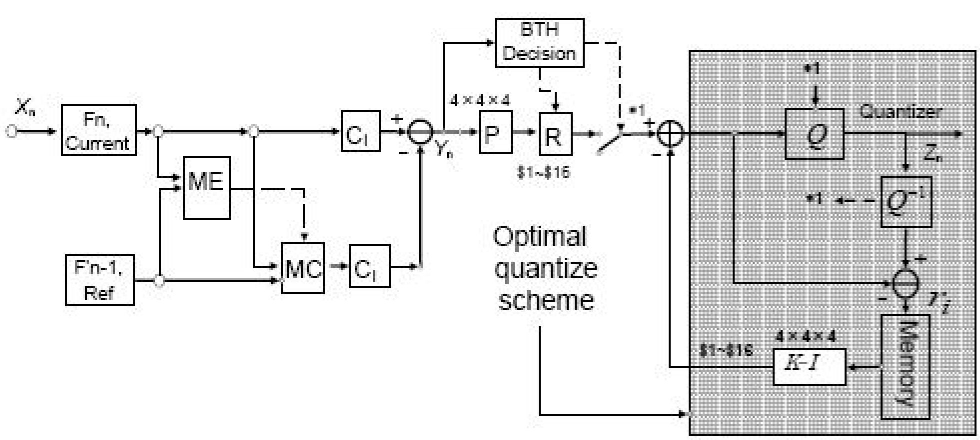

Figure1. Proposed coding Scheme

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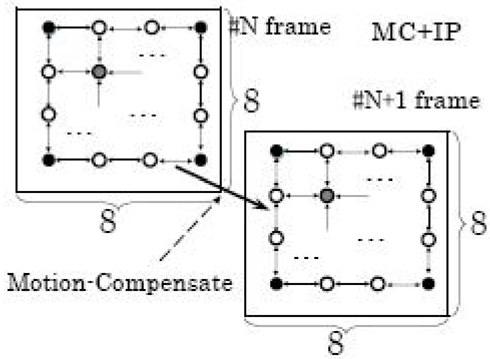

Figure 2. MC predictive coding with interpolative prediction

in the inter-block processing. Following Ref. 3, we have shown that non-causal prediction interpolation can be realized as a "transform coding", so the interpolation part can be considered as a "substitute" for an OT such as DCT.

The configuration of MC predictive coding with interpolative prediction is shown as Figure 2.

In our configuration, the predictive error *Yn* can be expressed as (1).

$$Y_n = C_I \times X_n - C_I \times f(X_{n-1}^{'}) = C_I \times (X_n - f(X_{n-1}^{'})) \quad (1)$$

Xn is the input 8×8 block signal plus four corner pixels and with 68×1 vector form after last order scanning; *X'n-1* is the reference vector in the last reconstruct frame at the exactly same position; *f (·)* means MC function, so *f(X'n-1)* is the vector of *X'n-1* after MC processing; C_I is the 68×68 predictive matrix, which can be expressed as follows:

$$C_I = \left[\begin{array}{ccccc|c} A_1 & & & & O & \\ A_3 & A_2 & A_3 & & & \\ & \ddots & \ddots & \ddots & & B \\ & & A_3 & A_2 & A_3 & \\ O & & & & A_1 & \end{array}\right] \quad (2)$$

$$A_1 = \begin{bmatrix} 1 & & & & \\ -\frac{1}{2} & 1 & -\frac{1}{2} & O & \\ & \ddots & \ddots & \ddots & \\ & O & -\frac{1}{2} & 1 & -\frac{1}{2} \\ & & & & 1 \end{bmatrix} \quad (3)$$

$$A_2 = \begin{bmatrix} 1 & & & & \\ -\frac{1}{4} & 1 & -\frac{1}{4} & O & \\ & \ddots & \ddots & \ddots & \\ & O & -\frac{1}{4} & 1 & -\frac{1}{4} \\ & & & & 1 \end{bmatrix} \quad (4)$$

$$A_3 = \begin{bmatrix} -\frac{1}{2} & & & & \\ & -\frac{1}{4} & & O & \\ & & \ddots & & \\ & O & & -\frac{1}{4} & \\ & & & & -\frac{1}{4} \end{bmatrix} \quad (5)$$

$$B^T = \begin{bmatrix} -1 & & 0 & & 0 & & 0 \\ 0 & O_{6\times4} & -1 & O_{48\times4} & 0 & O_{6\times4} & 0 \\ 0 & & 0 & & -1 & & 0 \\ 0 & & 0 & & 0 & & -1 \end{bmatrix} \quad (6)$$

A1, A2 and A3 are 8×8 matrices and shown as (3) ~ (5) Equations. B is a 4×64 matrix and (6) shows its transpose matrix, only at (1,1),(2,8),(3,57) and (4,64) position, the value equal to -1, at other positions the value equal to 0. *O* stands for the zero matrices.

Optimal Quantization Scheme

C. Optimal Quantization Scheme

The difference signals output by the interpolative process, which correspond to IP errors of the MC residuals, are sequentially input to the feedback quantizer [4]. Accordingly, coding errors resulting from the power expansion in the inter-block processing, due to having a non-orthogonal system, can be solved [4]-[5].

D. Conditional Pel Replenishment

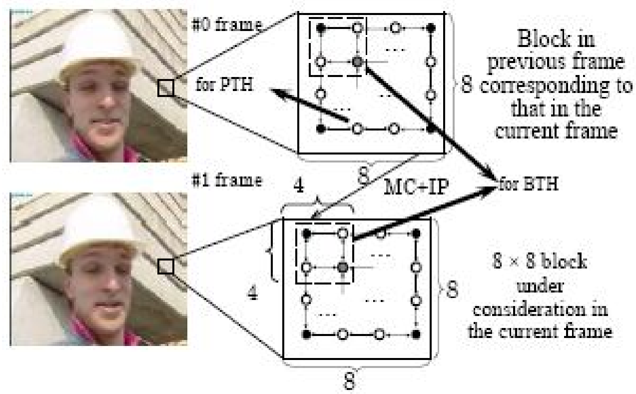

Figure 3. Conditional pel replenishment

As already mentioned, because an OT is not employed in our method, energy is not concentrated, but is distributed throughout an entire block. Consequently, determining whether pixels should be quantized is an issue. For this reason, we introduced conditional pel replenishment to the scheme.

As shown in Figure 3, the data of a previously decoded frame $F_{n-1}^{'}$, which are used for motion compensation, can also be used to perform reference of conditional replenishment pixel control before the current pixel data is quantized. As a result of pel replenishment, the transmission bandwidth is constrained.

Specifically, the decoded data of the previous frame are also processed by IP based on 8 × 8 blocks to obtain a set of reference values; and these values are compared with the predefined pixel threshold (PTH). As the reference values are obtained from the decoded data, this conditional pixel replenishment can be realized without additional overhead information.

On the other hand, the differences of IP outputs between current and previous frame (reference values) are then compared with the 4 × 4 sub-block threshold (BTH) (obtained by preliminary experiments). Thus, we determine whether the pixels should be quantized in the 4 × 4 sub-block of the 8 × 8 block under consideration in the current frame. At this moment, since the reference values are obtained from the decoded data, motion vector information (which the decoder has already gotten) and current 4 × 4 sub-block data (this information are not transferred to decoder yet), it is necessary to add the information for each 4 × 4 sub-block to certify whether it should be quantized or not. As a result, this conditional pixel replenishment can be realized with 1 bit (ON/OFF) additional overhead information for every 16 pixels (4 × 4 sub-block).

A threshold replenishment algorithm for adaptive vector quantization was first proposed by Fowler [6] in 1998, and has subsequently been used in various coding technology

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[7]-[10]. The proposed conditional pixel replenishment without codebook used in our method is based on that algorithm, because quantization is not performed on vectors, but on each individual pixel in an 8 × 8 block. Furthermore, the reference values are output of IP, not the distortion measure between code-vector and quantization input vector [6]. Therefore, computation of distortion measure for each block is not used. It means computational time of proposed method is less than Ref.6. However, the threshold values here are predefined and must be changed according to each frame of a video sequence. Improving the threshold selection process is considered to be an area of future work.

E. Rotation Scanning

In this paper, in order to realize the replenishment of pixels in the spatial domain, we proposed a new approach to improve the image quality. Input 8 × 8 block signal is reordered to adapt this sub-block system.

In feedback quantization system, the power of coding error can be expressed as (7)

$$E = \sum (f_i \cdot \sigma_{q_i}^2) \tag{7}$$

Here, *fi* is the feedback coefficient for one 8×8 block and $\sigma^2_{q_i}$ is the power of quantized error. When 4×4 sub-block conditionnal replenishment pixel is performed, non-significant sub-block will not be quantized, as a result, the power of quantized error in (6) is changed to the power of predict error. Generally, the power of quantized error is smaller than predict error. Therefore, if we could reduce the value of f_i at the non-significant sub-block position, we could suppress the increase of coding error power as show in (7). According to Ref.4, the value of f_i is defined by three matrices: the predictive matrix C_I; scanning order matrix *P*, and transform matrix *D*. Because OT is not applied in our system, matrix *D* has been determined; predictive matrix C_I defines the predict error, also has been determined.

When the scanning order is 4×4×4, as shown in Figure 4, 8×8 block f_i value is shown in Figure 5.

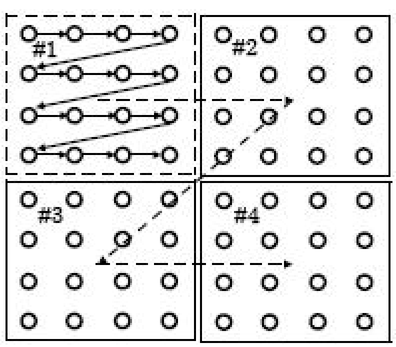

Figure 4. 4×4×4 scanning order

Each sub-block's $\sum f_i$ is shown as follow:

$$\begin{aligned} &\#1 \quad \Sigma(f_i) = 19.4527 \\ &\#2 \quad \Sigma(f_i) = 26.2304 \\ &\#3 \quad \Sigma(f_i) = 26.8412 \\ &\#4 \quad \Sigma(f_i) = 40.1022 \end{aligned} \tag{8}$$

Therefore, after deciding whether current 4×4 sub-block being quantized or not, for example, if #4 sub-blocks do not need to be quantized, as $\sum(f\,i)$ of #4 sub-block is the largest value of all sub-block, and according to the definition of distortion in feedback quantization system, as shown at (7), it is necessary to reorder the input signal to make sure non-significance sub-block could be quantized as early as possible. In Table I, shows this processing.

1.000	0.800	1.429	1.867	2.269	2.461	2.627	2.913
0.800	0.878	1.020	1.012	1.072	1.051	1.050	0.844
1.441	1.017	1.277	1.292	1.398	1.352	1.323	1.548
1.913	1.025	1.328	1.355	1.437	1.440	1.382	2.059
2.745	1.023	1.344	1.442	1.578	1.489	1.405	2.432
2.550	1.022	1.337	1.374	1.594	1.504	1.414	2.711
2.759	1.023	1.334	1.367	1.504	1.498	1.426	2.920
3.532	0.846	1.554	2.059	2.481	2.768	5.220	8.163

Figure 5. 8×8 block f_i value

TABLE I. ROTATION PROCESSING FOR ALL SITUATIONS

Before Rotation		After Rotation
$\begin{bmatrix}0&0\\0&0\end{bmatrix}\begin{bmatrix}0&0\\0&1\end{bmatrix}\begin{bmatrix}0&0\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}\begin{bmatrix}1&1\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&0\end{bmatrix}$	none	$\begin{bmatrix}0&0\\0&0\end{bmatrix}\begin{bmatrix}0&0\\0&1\end{bmatrix}\begin{bmatrix}0&0\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}\begin{bmatrix}1&1\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}$
$\begin{bmatrix}0&0\\1&0\end{bmatrix}\begin{bmatrix}1&0\\0&1\end{bmatrix}\begin{bmatrix}1&0\\1&0\end{bmatrix}\begin{bmatrix}1&0\\1&1\end{bmatrix}$	L	$\begin{bmatrix}0&0\\0&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}\begin{bmatrix}0&0\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}$
$\begin{bmatrix}0&1\\0&0\end{bmatrix}\begin{bmatrix}0&1\\0&1\end{bmatrix}\begin{bmatrix}1&1\\0&1\end{bmatrix}$	R	$\begin{bmatrix}0&0\\0&1\end{bmatrix}\begin{bmatrix}0&0\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}$
$\begin{bmatrix}1&0\\0&0\end{bmatrix}\begin{bmatrix}1&1\\0&0\end{bmatrix}\begin{bmatrix}1&1\\1&0\end{bmatrix}$	R^2	$\begin{bmatrix}0&0\\0&1\end{bmatrix}\begin{bmatrix}0&0\\1&1\end{bmatrix}\begin{bmatrix}0&1\\1&1\end{bmatrix}$

In Table I, we showed that depending on the insignificant / significant (expressed as 0 and 1 in various positions of 4×4 sub-block) appearance situation, how the rotation processing should be assigned. L means left rotation operation (counterclockwise rotation); while R means right rotation (clockwise); R^2 means right rotation twice and "none" means no rotation operation. However, there are two special circumstances in this Table, which marked with gray background: 0110 $\longrightarrow$ 0111 and 1001 $\longrightarrow$ 0111. It means after rotation operation, the last sub-block, #4, has been set to 1 mandatory on the basis of pre-experiment result.

By this rotation operation, the effect of improving coding efficiency is shown in Table II.

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F. Features of Proposed Scheme

The proposed inter-frame coding scheme has three characteristic features:

- An OT is not used.
- Conditional pel replenishment is performed without additional overhead information.
- A new hybrid coding framework, MC+IP combined with feedback quantization, is employed.

TABLE II. CODING EFFICIENCY IMPROVEMENT BY THE ROTATION OPERATION

Type	AppearanceFrequency(%)	PSNR before rotation (dB)	PSNR After rotaion (dB)	Entropy of Quantized value (bit/pixel)	Entropy of overhead (bit/block)
\$1: 0.0.0.0	33.71%	43.178	43.178	0	0.529
\$2: 0.0.0.1	5.177%	42.089	42.089	1.461	0.221
\$3: 0.0.1.0	5.619%	39.637	41.936	1.503	0.233
\$4: 0.0.1.1	3.725%	42.723	42.723	1.582	0.177
\$5: 0.1.0.0	4.735%	39.259	43.065	1.494	0.208
\$6: 0.1.0.1	3.535%	42.983	42.874	1.541	0.170
\$7: 0.1.1.0	2.146%	37.738	43.842	1.407	0.119
\$8: 0.1.1.1	3.788%	42.685	42.685	1.627	0.179
\$9: 1.0.0.0	4.987%	38.212	42.159	1.471	0.216
\$10: 1.0.0.1	1.199%	39.817	44.686	1.327	0.077
\$11: 1.0.1.0	3.220%	38.816	43.126	1.517	0.160
\$12: 1.0.1.1	3.283%	40.879	43.771	1.583	0.162
\$13: 1.1.0.0	3.283%	37.402	43.296	1.586	0.162
\$14: 1.1.0.1	4.735%	41.478	44.205	1.586	0.208
\$15: 1.1.1.0	3.914%	38.221	43.638	1.605	0.183
\$16: 1.1.1.1.	12.94%	44.555	44.555	1.698	0.382
Full-screen average	100.000 %	41.190	43.183	0.626	3.385

An OT is not used in our coding scheme; instead an IP method is adopted. In fact, an OT does not utilize the relations between pixels but merely transforms the signal from the spatial to frequency domain. In contrast, an IP method can compress the signal by eliminating the correlation between pixels within the frame. Generally, the MC prediction error is independent of time; however, a spatial correlation still exists. Accordingly, we have replaced the OT by an IP in our method, because in Ref. 3 we showed that IP can be achieved as a “transform coding”.

Conversely, non-orthogonally of the IP transform matrix means the power expansion problem, which means coding errors will be expanded when decoded, exists in the proposed method. As a result, feedback quantization is necessary.

III. SIMULATION

We now present simulation results obtained by using the proposed P-frame coding scheme and show a comparison between our method and the H.264 baseline [29]. To eliminate the influence of the I-frame, since its decoded image is used as the first reference frame when performing motion compensation, the first frame of the test sequence for the two methods is coded by the H.264 I-frame baseline under the same parameters values.

The first seven frames two CIF (352 × 288) test video sequence were served, foreman and bus, obtained from YUV Video Sequences website [11]. The MC coding parameters (both methods are the same at this point) are set as follows:

- Search range: 32 pixels.
- Total number of reference frames: 1.
- ME scheme: fast full search.
- PSliceSearch8x8: 1 (used, all other types are not used).
- DisableIntraInInter: 1 (Disable Intra mode for inter slice).
- Rate-distortion-optimized mode decision: used.

Besides these parameters, the threshold values of the proposed scheme are adapted according to the input frames.

A. Comparison of Prediction Errors

TABLE III. STATISTIC VALUES OF RESIDUAL SIGNALS

Test Image	Characteristic Value					
	Number of 0’s		Average Error		Entropy	
Foreman	PM	H.264	PM	H.264	PM	H.264
	35325	16862	9.66	15.48	3.249	3.829

A comparison between the prediction errors in the results is first shown. Through this comparison, we can see the distribution of the errors obtained by the proposed scheme and whether spatial correlation exists in the signal after motion compensation. Table b! lists several statistical values for both methods that reflect the distribution of their residual signals.

In this table, “PM” stands for “proposed method”; Entropy is calculated based on Shannon theory and “Average Error” is the average value of two signal powers. Number of 0’s means how many pixels are accurately predicted.

Figure 6 shows the prediction errors of the first P-frame at each pixel position when using the first frame of *foreman.cif* as a test image. Here, the x-axis expresses the pixel position and the y-axis expresses the value of prediction error.

The distribution of the prediction errors for the proposed method is clearly more concentrated around zero than that for H.264, and the residual signal power is about 37.6% lower under the proposed method. Therefore, we consider that our scheme provides improved coding efficiency if an appropriate quantization method is employed.

B. Comparison of Coding Efficiency

Next, we show the coding results of the proposed method

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and H.264. As stated before, the threshold values in our method must be changed for each frame, and these thresholds are obtained by a preliminary experiment. Since PTH and BTH are typically within a certain range, the results presented here are also limited. For this reason, the conditional pel replenishment used here has the potential for improvement.

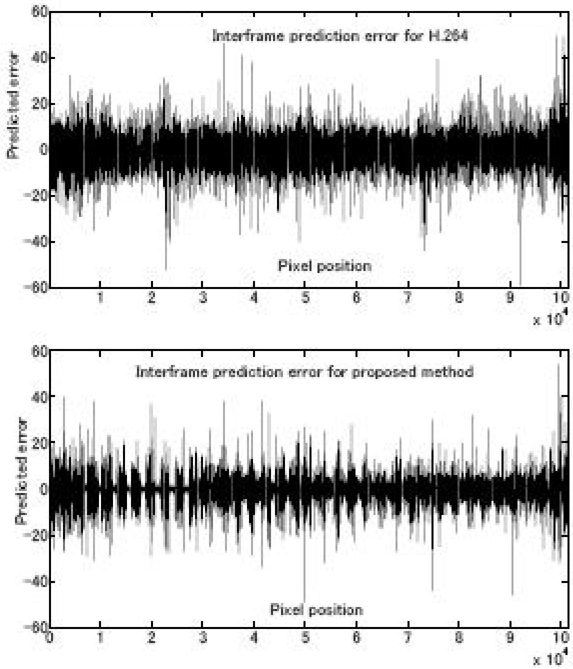


Figure 6. Comparison of prediction errors

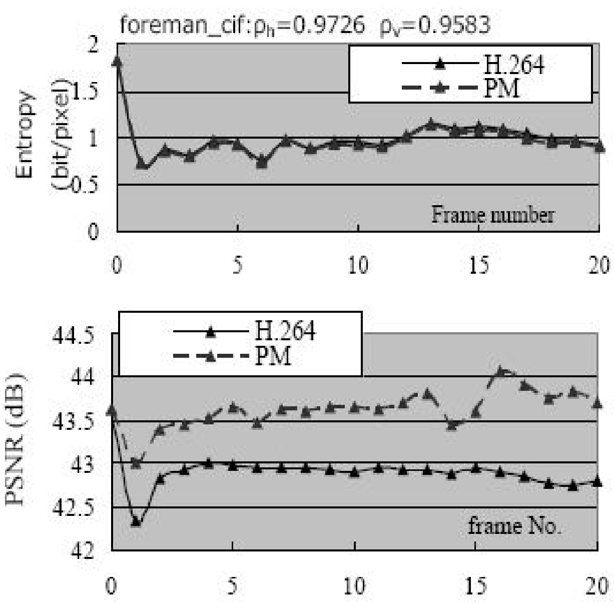


Figure 7. Comparison of coding effciency for foreman.cif

Figure 7 ~ 10 show comparisons between the methods' coding efficiency for the test sequences of foreman, bus, flower and highway, respectively. ñh and ñv means the correlation of test image in the horizontal and vertical direction respectively.

In these plots, the horizontal axis expresses the frame number of the coded frames (0–20 frames for foreman.cif and 0-10 frames for other test sequences) and the vertical axes express the entropy (bit/pixel; upper plot) and peak signal-to-noise ratio (PSNR; dB; lower plot) of each test image. Although the number of bits required by the proposed method (its entropy) is approximately equal to that of H.264, PSNR for the proposed method is consistently higher (the average improvement is about 0.3–2 dB).

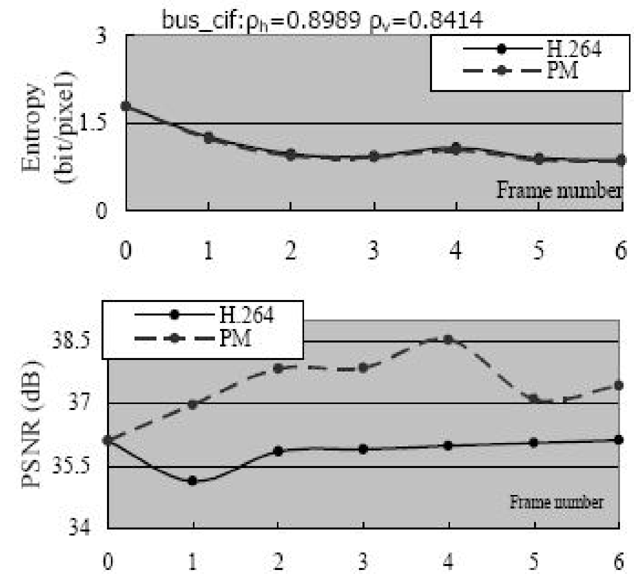


Figure 8. Comparison of coding efficiency for bus.cif

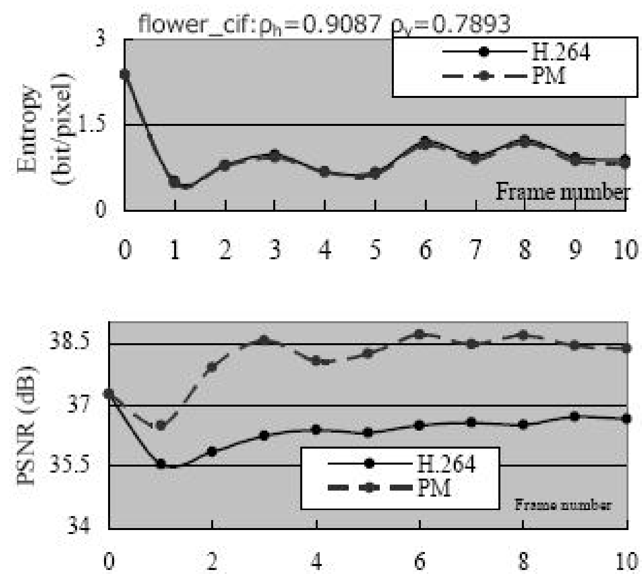
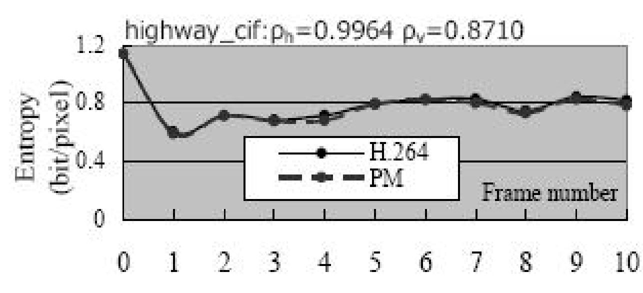


Figure 9. Comparison of coding efficiency for flower.cif



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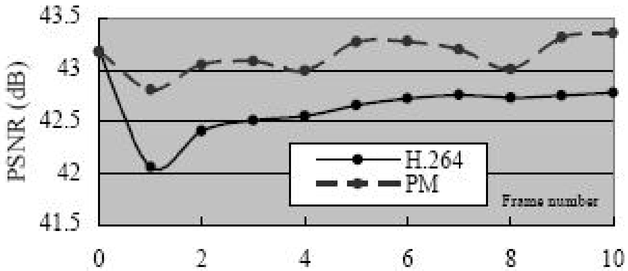

Figure 10. Comparison of coding efficiency for highway.cif

Table IV shows the coding results when the proposed method is applied to the bus CIF video sequence. Here, Q(.) is the average entropy of all pixels in the frame; H(.) expresses the overhead (motion vectors) entropy.

TABLE IV. CODING RESULTS OF PROPOSED METHOD

P-frame Number	THB	$H(S)$ (bit/pixel)	$Q(S)$ (bit/pixel)	$PSNR(dB)$
1	50	0.131	1.098	36.980
2	45	0.079	0.859	37.841
3	45	0.076	0.843	37.854
4	40	0.076	0.964	38.529
5	40	0.074	0.797	37.106
6	45	0.073	0.770	37.437

TABLE V. ENTROPY OF MOTION VECTORS

(bus)			highway	
Frame NO.	H.264	PM	H.264	PM
1→2	0.131	0.048	0.079	0.080
2→3	0.080	0.047	0.077	0.082
3→4	0.074	0.046	0.074	0.083
4→5	0.091	0.075	0.074	0.090
5→6	0.072	0.072	0.081	0.087
6→7	0.070	0.074	0.080	0.092
7→8	0.077	0.076	0.085	0.085
8→9	0.074	0.135	0.075	0.087
9→10	0.078	0.098	0.079	0.084

C. Comparison of Motion Vectors

Table V lists the entropy of motion vectors in each frame for the two methods. Moreover, Figure 11 shows the decoded frame obtained by the two methods for four test sequences, where lines denote the motion vectors. The proposed method clearly contains smaller amount of motion-vector information than H.264. Furthermore, corresponding decoded frames without motion vectors are shown in Figure 12.

D. Effect of Adaptive coding between intra/inter mode

In Figure 13, shows the simulation results of the adaptive coding between inter / intra coding mode. Insertion of the PinP (Picture in Picture configuration, as shown in Figure 14) is set to start at the first frame and completed at the eighth frame. In Figure 13, PSNR of "inter mode only" means the value of PSNR when all frames from the second one are forced

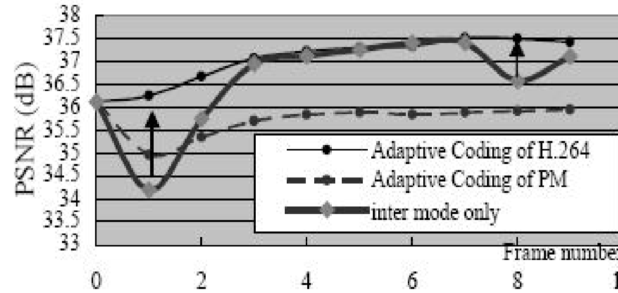

Figure 13.Coding Efficiency for Adaptive Mode Selection

Figure 14.PinP Configuration

to be codes as inter frame mode and the amount of transmission bit is almost the same to the proposed adaptive scheme.

If the coding mode is fixed to inter coding, as shown here, the improvement of coding efficiency begin at the second P-frame and after coding 2 frames, the efficiency is closer to the adaptive system eventually. The arrow in this figure expressed how much improvement can be achieved by proposed adaptive scheme.

On the other hand, because adaptive intra/inter mode selection method with overhead information has been applied in H.264 standard, when using the PinP test sequence shown in Figure 14, significant decrease in PSNR does not befall.

In addition, in the H.264 scheme, because intra-frame coding mode can be selected at any time throughout the entire coding period, the overhead for every macro-block is about 0.01 bit/pixel more than proposed method. However, the disadvantage of proposed method is that adaptive mode selection is not flexible enough. In the future, authors will do the improvement at this point.

CONCLUSIONS

In this paper, we proposed a new inter-frame coding scheme in which the OT (e.g., a DCT) used in conventional hybrid coding schemes is replaced by a non-causal IP. Application of this IP can potentially reduce the amount of signal

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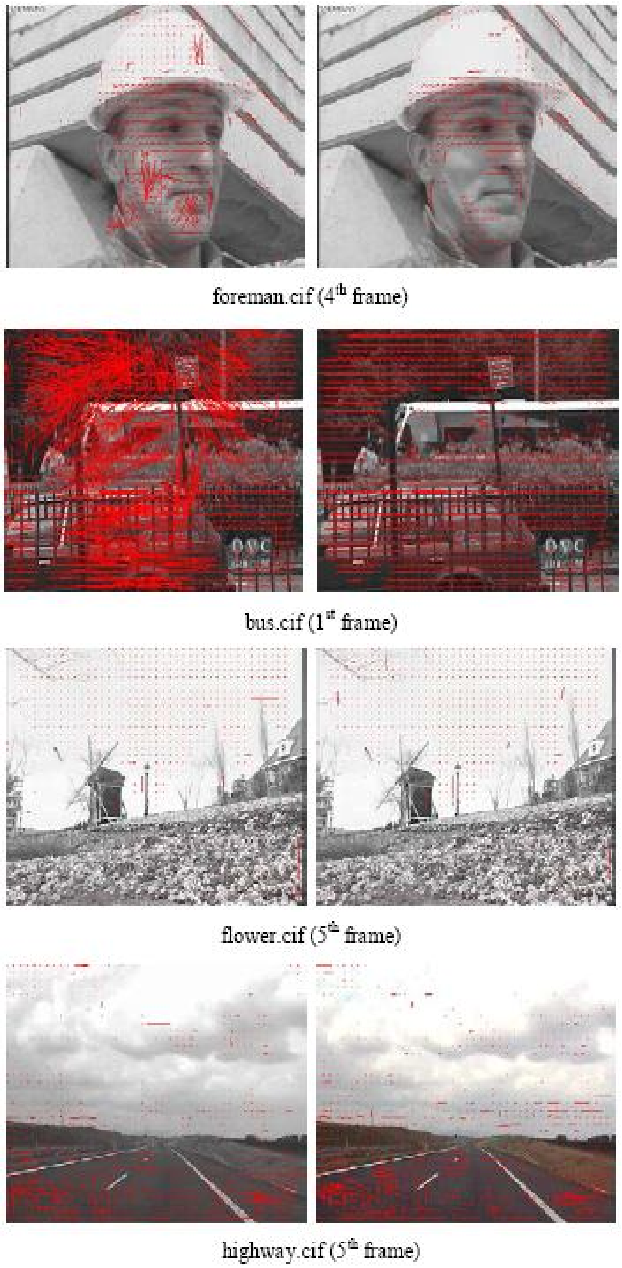

Figure 11. Comparison of motion vectors for the decoded frame obtained by (left) H.264 and (right) the proposed scheme

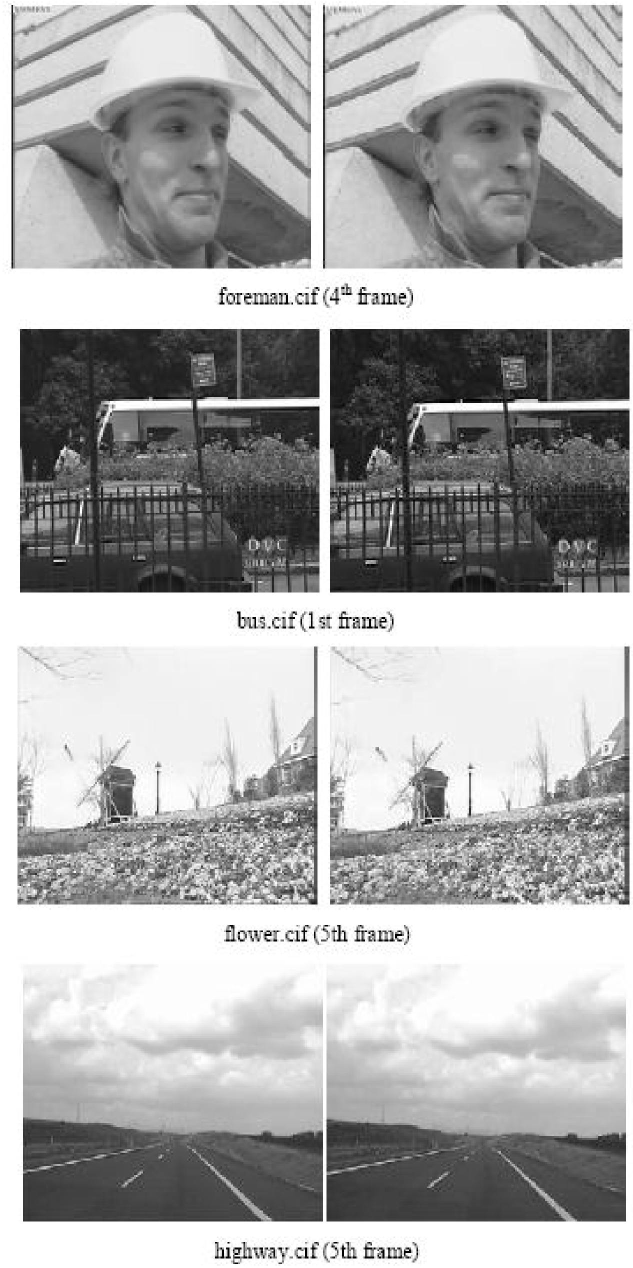

Figure 12. Comparison of decoded frame obtained by (left) H.264 and (right) the proposed scheme

power a priori. Since IPs make use of the spatial correlations between pixels, we consider them more effective than OTs (which merely perform domain transforms) for residual data that has been compressed after MC inter-frame prediction. However, combining our method with an OT is also of great research interest, as shown in Section II of this paper. As a result, we have also introduced conditional pel replenishment to our scheme. Moreover, no additional overhead information is added by employing this method. Our model thus has the three characteristic features shown in Section IIF. A comparison between the simulation results of the proposed method and H.264 in Section III, showed that when using four test sequences a, the proposed scheme achieves an approximate 0.3–2 dB improvement for an entropy similar to that of the H.264 baseline level.

As future work, the conditional pel replenishment method utilized in our scheme must be improved, and this should be addressed first. Other areas that should also be explored are whether the proposed scheme can maintain high coding efficiency if the test sequence becomes large.

In conclusion, we have introduced a different approach for P-frame hybrid coding that utilizes the spatial correlation of the MC residual signal. Since our hybrid video coding method achieved high coding efficiency without employing an OT, we have shown the feasibility of non-orthogonal transforms for effective coding.

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